EFFICIENT CHARACTERIZATION OF UWB ANTENNAS USING THE FDTD METHOD

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ABSTRACT

In this paper we present a method for the efficient characterization of UWB antennas based on a combination of FDTD simulation and the Lorentz reciprocity principle. In order to obtain a complete spatio-temporal characterization it is sufficient to determine the transmit transfer function by using first a single numerical simulation of the antenna in transmit mode in only a small nearfield region followed by a nearfield to farfield transformation. The application of the Lorentz reciprocity theorem then yields the receive transfer function from the transmit transfer function. The transfer functions of the antenna allows the calculation of all quality measures of interest either in the frequency domain or the time domain. The proposed method is validated by a comparison of its results with an EMPIRE™ FDTD simulation of an entire two antenna system.

INTRODUCTION

The development of ultra wideband systems e. g. for the wireless multimedia data communication between different home entertainment systems (DVD player, flat screen, Internet PC, …) becomes very appealing since the FCC opened the spectrum from 3.1 GHz to 10.6 GHz for the unlicensed low-power use [1].

The demands for the antenna of such a system is not only limited to large bandwidth. Other quality criteria like low ringing and gain stability over the frequency range are often requested [2]. Typically these parameters have to be assessed by broadband measurements in anechoic chambers and therefore requires a certain infrastructure and effort.

Especially for the design of systems entailing different antenna integration scenarios it is essential to have a fast and easy access to these measures by simple numerical simulations. With this regard, the FDTD (Finite Difference Time Domain) method is well suited for such computations due to the fact that a large frequency spectrum can be investigated simultaneously. In this paper we present a simple method to obtain a complete spatial-temporal characterization of an antenna by performing a single simulation of a transmitting antenna in a small nearfield region.

THEORY

From a signal processing point of view the antenna can be considered a LTI (Linear Time-Invariant) system which can be fully characterized by its transfer function [3]. This can be expressed by

$$\frac{\mathbf{E}_2(\mathbf{r}_2,\omega)}{\sqrt{Z_{F0}}} = \frac{U_{1,in}(\omega)}{\sqrt{Z_L}} \mathbf{A}_{TX}(\hat{\mathbf{r}}_{12},\omega) \frac{e^{-jk_0 r_{12}}}{\sqrt{4\pi} r_{12}} . \quad (1)$$

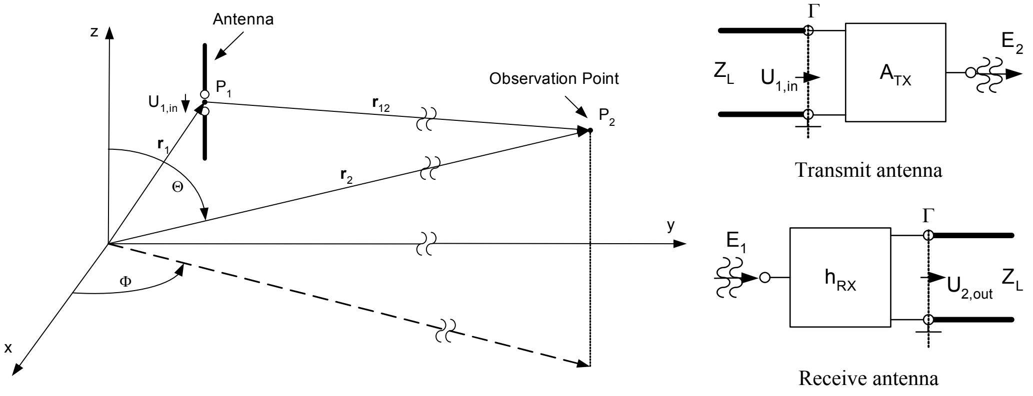
In (1) denotes $\mathbf{E}_2(\mathbf{r}_2,\omega)$ the electric field strength at a point $\mathbf{r}_2$ in the farfield of the antenna at $\mathbf{r}_1$ which is excited by an incoming voltage $U_{1,in}(\omega)$ at the antenna port (see Fig. 1). While $e^{-jk_0 r_{12}} / \sqrt{4\pi} r_{12}$ describes the propagation of the wave from the antenna to the observation point in the direction $\mathbf{r}_{12}$, $\mathbf{A}_{TX}(\hat{\mathbf{r}}_{12},\omega)$ represents the transmit transfer function of the antenna. In (1) Z_{F0} and Z_L are the free space and feed line impedance, respectively and $\hat{\mathbf{r}}_{12} = \mathbf{r}_{12}/r_{12}$ is the unit vector from the antenna to the observation point. Consequently $\mathbf{A}_{TX}(\hat{\mathbf{r}}_{12},\omega)$ is independent from the distance between the antenna and the observation point but one has always to take into account that the definition of the transfer function according to (1) requires local plane wave propagation and thus is related to farfield conditions only.

On the other hand, following [3] the reception of the antenna from an incident plane wave can be expressed by

$$\frac{U_{2,out}(\omega)}{\sqrt{Z_L}} = \sqrt{4\pi}\,\frac{\mathbf{E}_{1,inc}}{\sqrt{Z_{F,0}}}\,\mathbf{h}_{RX}(\hat{\mathbf{k}},\omega)\cdot \tag{2}$$

In (2) denotes $U_{2,out}(\omega)$ the voltage traveling out of the antenna into the receiving system if the antenna is exposed to a plane wave. Note that $\mathbf{E}_{1,inc}$ is the electric field strength of an incident plane wave, i. e., the field in absence of the antenna. With this definition $\mathbf{h}_{RX}(\hat{\mathbf{k}},\omega)$ can be considered as the receive transfer function of the antenna.

Fig. 1 illustrates the above definitions:



a) Definition of the coordinate system (transmit antenna). b) Transfer functions.

Fig. 1: Representation of the antenna as a LTI system for transmit and receive mode.

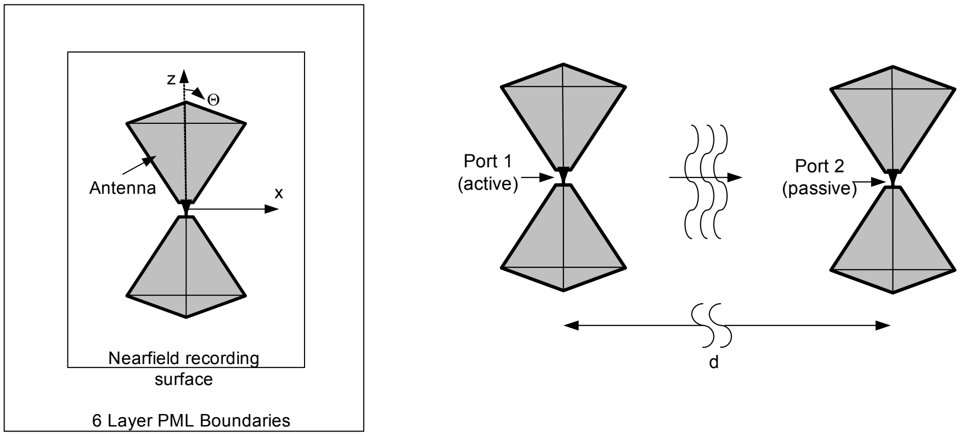
Both, transmit and receive transfer functions are related to each other by Lorentz theorem of reciprocity. An expression that takes into account the ultra wideband properties of the system has been derived in [3]:

$$2j\omega\mathbf{h}_{RX}(-\hat{\mathbf{k}},\omega) = c_0\mathbf{A}_{TX}(\hat{\mathbf{k}},\omega) \tag{3}$$

Coming back to the purpose of our investigation this means that it is sufficient to calculate the transmit transfer function on the basis of a FDTD simulation in order to fully characterize the antenna.

RESULTS

In order to prove the above derived method a biconical antenna is analyzed. The antenna is designed to operate in the frequency range above 3.1 GHz. For the FDTD simulation the antenna is modeled with all necessary details. PML (Perfectly Matched Layer) absorbing boundaries are positioned in the nearfield of the antenna. The distance to the PML boundaries is less than $\lambda/4$ at the lowest frequency of interest thus resulting in a time and memory efficient simulation. The antenna is excited by a broadband Gaussian pulse centered at 0 Hz and having a half bandwidth of 20 GHz with reference to a signal decrease of 20 dB. The nearfield of the antenna is recorded at every 200 MHz between 1 GHz and 20 GHz on a Huygens surface enclosing the antenna. The EMPIRE^{TM} [4] software package uses this nearfield data to derive equivalent electric and magnetic sources on the surface and extrapolate the field strength in the farfield. The total simulation time, including the post-processing of the farfield data, takes only a few minutes on a standard 2 GHz PC. The results from this simulation are used to process the transmit and receive transfer functions of the antenna according to the above mentioned method. To validate the approach a second simulation model is set up that consists of two biconical antennas separated by distance of $d = 50$ cm. While the first antenna is fed by the Gaussian pulse the second antenna is passive and receives the radiated pulse from the field. Therefore it is possible to calculate the transmission between both antennas in terms of s_{21}.



a) Setup of a single antenna simulation.
b) Transmission between two antennas.

Fig. 2: Setup for one-antenna simulation and transmission between two antennas.

In addition to the direct calculation of s_{21} based on the complete FDTD simulation of two antennas, we can also use the transfer functions from the one-antenna simulation and calculate the transmission between two antennas by the following expression [3]:

$$s_{21}(\omega) = \left.\frac{b_2}{a_1}\right|_{a_2=0} = \mathbf{A}_1\left(\hat{\mathbf{k}}_{12},\omega\right)\mathbf{h}_2\left(\hat{\mathbf{k}}_{12},\omega\right)\frac{e^{-jk_0 d}}{d} \tag{4}$$

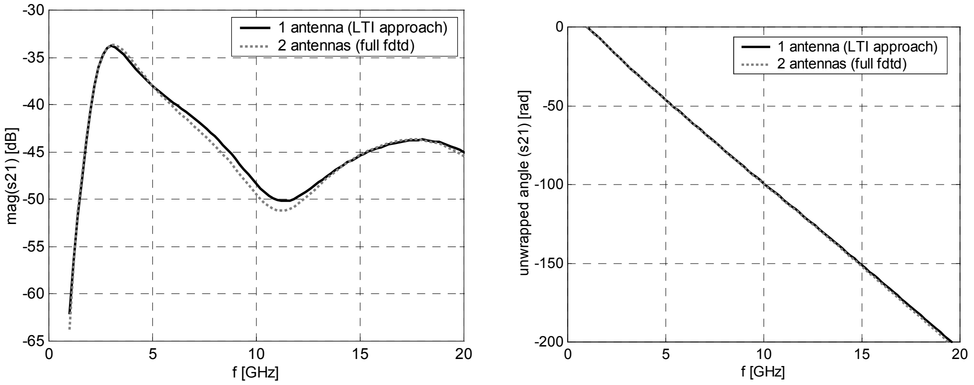
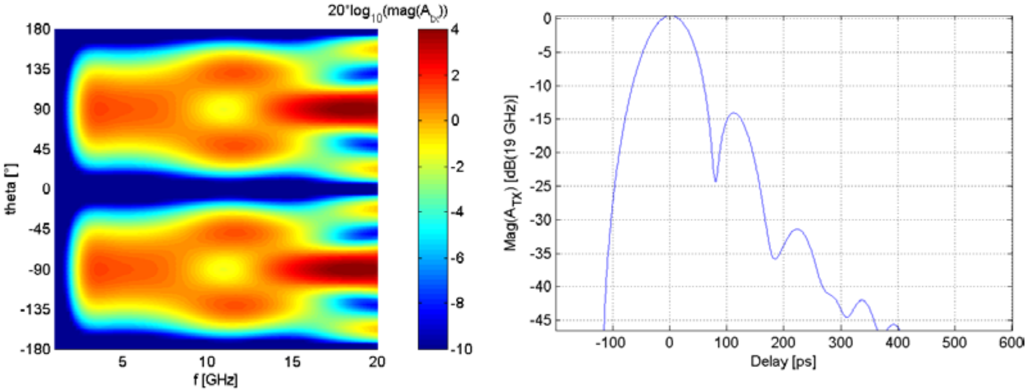


Fig. 3: Transmission between two antennas calculated by the complete FDTD simulation of two antennas and the FDTD simulation of a single antenna combined with a LTI approach.

Fig. 3 compares the results from both methods and shows a good agreement. This proves that the method described above has been implemented in the correct way. In addition to the validation aspect of such a calculation it should be noted that it is now possible to fully characterize an antenna by a simple single nearfield FDTD simulation of the transmitting antenna. Furthermore the TX- and RX-transfer functions can be used e. g. for later propagation simulations using other simulation tools.

Coming back to the characterization of the single antenna Fig. 4a illustrates the TX transfer function of the biconical antenna in the E-Plane. It can be observed that the antenna is matched above 3 GHz. The characteristics reminds of a simple 1st order dipole until a frequency of 8 GHz. For higher frequency the characteristic changes showing sidelobes and gain deviations. Fig. 4b shows the magnitude of the baseband impulse response of the antenna for θ=90°, giving a clear indication of the *ringing* behavior of the antenna. The impulse response has been determined using a Kaiser-Bessel frequency domain window.



a) Transfer function in the E-plane.

b) Time domain impulse response for θ = 90°.

Fig. 4: TX characteristics of the biconical antenna.

CONCLUSION

We have shown that full spatial-temporal characterization (both transmit and receive characteristics) of an antenna can be obtained by a single nearfield FDTD simulation of the transmission case followed by a farfield transformation in combination with the exploitation of the reciprocity principle. The approach has been validated by a comparison with the transfer function of a two antenna system determined by a full scale FDTD simulation.

Based on the transfer functions of the antenna all relevant quality measures of UWB antennas can be calculated.

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